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Sveriges Lantbruksuniversitet **Skara 2018** **Rapport 49**
Institutionen för husdjurens miljö och hälsa

Swedish University of Agricultural Sciences ***Report 49***
Department of Animal Environment and Health

ISSN 1652-2885

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Executive summary of scientific final report

Front photo: Anne Larsen, SLU

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Summary

Handling for slaughter inevitably exposes production animals to welfare risks and can be the most stressful event in their lives. Most animals experience significant stress just before and during the slaughter. Strong or prolonged stress leads to reduced animal welfare and can also influence meat quality. The project aimed at contributing to the development and evaluation of systems for slaughter of cattle to achieve as good animal welfare and meat quality as possible. One mobile and one stationary slaughter plant were studied. The mobile plant had capacity for about 4 animals per hour or 30-35 animals per day and the stationary about 45-50 animals per hour or 290-320 animals per day. The mobile plant including the cooling unit and staff spaces was built into two trucks with trailers. Observations of mobile slaughter of 296 animals were performed on 17 days during slightly more than one year in 2016-2017 at 15 cattle farms in southern and central Sweden. On 17 days during the same period, observations of stationary slaughter of 296 animals from 144 farms were carried out. The observations were related to animal handling when driving to the stun box, animal behaviour in the driveway to the stun box and in the stun box, blood chemistry at bleeding, carcass characteristics immediately after slaughter, veterinary inspection findings, meat quality characteristics in the sirloin after 7 days hanging, and events that might have affected the slaughtering process. The studies did not cover the transport to or the stay at the stationary plant before slaughter. The observed part of the driveway was 2.4-5.7 m long at the mobile plant and 7.3 m at the stationary plant. In both abattoirs a cartridge-driven penetrating captive bolt weapon was used to stun the animals and after stunning the animals were bled by thoracic sticking. The treatment of the carcasses differed in several ways between the slaughter plants. In 29 multivariable statistical models the effects of different animal and farm factors were studied. Most animals were driven a few times and only a small number of animals were driven many times. Similarly, there were a smaller number of animals that exhibited many stress-related behaviours, while most only showed few such behaviours. The project shows the importance of the animals being calm when driving to the stun box begins, that the layout of the premises, driveways and equipment is appropriate, and that the handling of the animals during driving, stunning and bleeding is correct. The differences between the plants were relatively few and were mainly due to factors specific to the plants studied, rather than general differences between mobile and stationary slaughter in general. There are options for good animal welfare and meat quality in both mobile and stationary slaughter of cattle. It is not possible to conclude that animal welfare or meat quality is generally better with one or the other way of slaughtering. Recommendations are given to the operations managers to achieve a reduced proportion of animals in overnight lairage at the stationary plant, improved animal handling on farm and at driving into the stun box, improved design of the stun box at the mobile plant to facilitate quick and accurate shooting, hoisting and bleeding of animals, reduce the risk of re-shooting and long sticking times, possibilities for the staff to communicate between the inside and outside of the mobile plant in order to avoid disturbing sounds in sensitive driving situations, as well as a more permanent circle of suppliers of animals to the mobile plant in order to reduce the variation in farm conditions and animals, and improve the possibilities for establishing well-functioning on-farm routines in preparation for slaughter.

Sammanfattning

Hanteringen inför slakt utsätter oundvikligen produktionsdjuren för välfärdsrisker och kan utgöra den mest stressfyllda händelsen i deras liv. De flesta djur upplever betydande stress strax före och i samband med slakten. Stark eller långvarig stress leder till sänkt djurvälfärd och kan dessutom gå ut över köttkvaliteten. Projektet syftade till att bidra till utvecklingen av och att utvärdera system för slakt av nötkreatur för att uppnå en så god djurvälfärd och köttkvalitet som möjligt. Ett mobilt och ett stationärt slakteri studerades. Det mobila slakteriet hade kapacitet för ca 4 djur per timme eller 30-35 djur per dag och det stationära ca 45-50 djur per timme eller 290-320 djur per dag. Det mobila slakteriet inklusive kylenhet och personalutrymmen var inhyst i två långtradare med släp. Observationer av mobil slakt av 296 djur utfördes 17 dagar under drygt ett års tid 2016-2017 på 15 leverantörsgårdar i södra och mellersta Sverige. Sjutton dagar under samma period utfördes observationer av stationär slakt av 296 djur från 144 leverantörsgårdar. Observationerna rörde djurhantering vid drivning till skjutboxen, djurbeteende i drivgången till skjutboxen och i skjutboxen, blodkemi vid avblodning, slaktkroppsegenskaper direkt efter slakt, veterinära slaktanmärkningar, köttkvalitetsegenskaper i ryggbiffen efter 7 dagars hängmörning, samt händelser som kunde tänkas ha påverkat slaktprocessen. Studierna omfattade inte transporten till eller vistelsen på det stationära slakteriet före slakten. Den observerade delen av drivgången var 2,4-5,7 m lång på det mobila slakteriet och 7,3 m på det stationära. På båda slakterierna användes en krutdriven penetrerande bultpistol för att bedöva djuren och efter bedövning avblodades djuren genom bröststick. Hanteringen av slaktkropparna skilde på flera sätt mellan slakterierna. I 29 multivariabla statistiska modeller studerades effekten av olika djur- och gårdsfaktorer. De flesta djur drevs ett fåtal gånger och endast ett litet antal djur drevs många gånger. På samma sätt var det ett mindre antal djur som uppvisade många stressrelaterade beteenden medan de flesta bara uppvisade få sådana beteenden. Projektet visar betydelsen av att djuren är lugna när indrivningen i skjutboxen påbörjas, att utformningen av lokaler, drivvägar och utrustning är lämplig och att hanteringen av djuren vid drivningen, bedövningen och avblodningen är korrekt. Skillnaderna mellan slakterierna var relativt få och i huvudsak sannolikt orsakade av enskilda faktorer på de studerade anläggningarna, snarare än generella skillnader mellan mobil och stationär slakt i allmänhet. Det finns förutsättningar för god djurvälfärd och köttkvalitet i såväl mobil som stationär slakt av nötkreatur. Det går inte att säga att djurvälfärden eller köttkvaliteten generellt blir bättre med det ena eller andra sättet att slakta. Rekommendationer ges till de verksamhetsansvariga på de studerade slakterierna för att uppnå en minskad andel djur som övernattar på det stationära slakteriet, en förbättrad djurhantering på gårdarna och vid indrivningen i skjutboxen, en förbättrad utformning av skjutboxen på det mobila slakteriet för att underlätta snabb och korrekt skjutning, länkning och stickning av djuren, minska risken för omskjutning och långa sticktider, möjligheter för personalen att kommunicera mellan det mobila slakteriets insida och utsida för att undvika störande ljud i känsliga drivningssituationer, samt en mer permanent krets av leverantörer av djur till det mobila slakteriet för att minska variationen i gårdsförhållandena och djur samt förbättra möjligheterna att skapa väl fungerande rutiner inför slakt på gårdarna.

Introduction

Handling for slaughter inevitably exposes production animals to welfare risks and can be the most stressful event in their lives. Although efforts have been made to reduce animal suffering in transport and slaughter, most farm animals still experience significant stress just before and during slaughter (Warriss, 1990; Cockram and Corley, 1991). Strong or prolonged stress leads to reduced animal welfare.

Animal husbandry in Sweden and several other countries has been extensively restructured for decades. Average herd sizes increase and the animals are given less time for human contact during rearing, which may make them less tolerant of handling at the time for slaughter (Bunzel-Drueke et al., 2009). The industrialised slaughter also changes, leading to fewer and larger plants. The transports from farm to plant thus risk becoming longer and the number of animals slaughtered per unit of time increases, which may constitute additional animal welfare risks. Therefore, the importance of good slaughter systems and procedures to ensure animal welfare and minimise animal stress increases.

Examples of potentially stressful situations are handling by foreign people, rough loading and unloading, long transports in uncomfortable conditions, waiting and possible overnight lairage at the slaughterhouse, insufficient access to water and feed, mixing with unfamiliar animals, unfamiliar environments and smells, sudden climate changes and strong noise. The degree of animal impact is likely to depend on the nature, intensity and duration of different negative stimuli in combination with the susceptibility of the animals to such stimuli (EFSA, 2004; Algers et al., 2009; Dalla Villa et al., 2009).

In addition to reducing animal welfare, stress associated with slaughter may impair the quality of meat by consuming glycogen reserves in the muscles (Ferguson et al. 2001; Hambrecht et al., 2003; Gregory and Grandin, 2007; Warner et al., 2007; Ferguson and Warner 2008). The most important meat quality defect in cattle is DFD (dark, firm and dry) or dark-cutting beef, which causes significant financial losses to the meat industry (Scanga et al., 1998; Shen et al., 2009; Warren et al. al., 2010). DFD occurs when the glycogen reserves of the muscle are emptied before the moment of death due to physical activity or prolonged and severe stress, resulting in a high final pH (over 5.8) and a dark, dry and sugary meat. Management-related injuries to slaughtered animals can also lead to meat rejection and lower slaughter weights (Jarvis et al., 1996; Huertas et al., 2010).

Studies have shown that animal welfare in commercial slaughter varies considerably and in some cases is unacceptably weak (Atkinson, 2007; Gregory et al., 2007; Berg and Axelsson, 2010; von Wenzlawowicz et al., 2012; Atkinson et al., 2013). The use of electric goads to drive the animals into the stun box is common in stationary slaughter (Berg and Axelsson, 2010). Atkinson (2009) and Hultgren et al. (2014) found a connection between rough handling and behavioural stress reactions in the animals. In a study of six Swedish slaughterhouses, between 7 and 35% of the cattle were found to be inadequately stunned at the first shot (Atkinson and Algers, 2009). Atkinson et al. (2013) observed that bulls and calves are the categories of animals most often stunned in an inadequate manner. In a study conducted at a Swedish slaughter plant, 17% of the 585 bulls studied were not adequately stunned (Atkinson et al., 2013). There is reason to believe that differences in several respects exist even between stationary and mobile slaughter.

An effective way of reducing the stress associated with slaughter is considered to ensure that the abattoir design and equipment allow for efficient propulsion of the animals, and that the stockpersons understand the principles for this (Grandin, 1996). Stockpersons and other personnel at the slaughterhouse may be under pressure of a high speed of slaughter or have difficulties in carrying out their work due to improperly designed premises, and may therefore feel forced to use rough driving methods. However, this may increase the stress of the animal and trigger inappropriate behaviours such as crowding, moving backwards or attempting to escape, which further complicates the work. Coleman et al. (2003) found a connection between the slaughterhouse staff attitude and the way of driving the animals, as stockpersons with negative attitudes showed more aggression against the animals, in accordance with the theory of planned behaviour (Ajzen, 1985; 1991). Investments in equipment for mechanical driving and head restraint during pneumatic bolt stunning have been shown to dramatically reduce stressful behaviour in the animals and the use of electric goads (Atkinson, 2009). Wiberg (2012) believed that well-designed driveways at the slaughterhouse facilitate a smooth flow of animals, reducing the risk of violent driving methods.

In parallel with the mentioned development towards fewer and larger stationary slaughter plants, there is growing interest in small-scale farm slaughter. Such slaughter may have the potential to reduce the stress that the animals experience just before slaughter by shortening or completely eliminating the transport to the plant, reducing exposure to unknown environments, animals and persons, and slowing down line speed. Hultgren et al. (2016) conducted a risk assessment of animal welfare in connection with small- and large-scale sheep slaughter and found that welfare risks were lower for small-scale slaughter for most factors, but the opposite was true for factors involving regrouping and handling of single animals.

A mobile slaughterhouse is a complete self-contained plant that can be moved between different farms. Prototypes for such plants have been developed and approved in several countries, including Britain, the United States, Canada, Norway and Sweden. It is likely that cattle are sometimes slaughtered in mobile units in several countries in Europe.

The EU Regulation on the protection of animals at the time of killing (European Council, 2009) provides for derogations from certain requirements for mobile slaughterhouses, with the following justification in the introductory recitals to the Regulation, no. 40: ”*Mobile slaughterhouses reduce the need for animals to be transported over long distances and therefore may contribute to safeguarding animal welfare. However, technical constraints for mobile slaughterhouses differ from fixed slaughterhouses and technical rules may need to be consequently adapted. Therefore, this Regulation should provide for the possibility to establish derogations exempting mobile slaughterhouses from the requirements on layout, construction and equipment of slaughterhouses. Pending the adoption of such derogations, it is appropriate to allow Member States to establish or maintain national rules regarding mobile slaughterhouses.*” Derogations can thus be granted from the provisions of Annex II of the Regulation on the layout, construction and equipment of slaughterhouses.

The effects of mobile slaughter on animal welfare and meat quality have so far not been scientifically studied to a large extent. During 2013-2014, a Swedish company developed a mobile slaughterhouse for commercial slaughter of large cattle in Sweden. With the aid of the facility, slaughter is carried out on farms in most parts of the country. The business provides opportunities for scientific studies of mobile slaughter.

Objectives and aims

The objective of the project was to contribute to the development and evaluation of cattle slaughter systems to achieve as good animal welfare and meat quality as possible without compromising food safety and biosecurity. More specifically, the project aimed at:

1. Compare the conditions for good animal welfare and meat quality at mobile and stationary slaughter of cattle.
2. Propose changes in slaughter routines and animal management in mobile and stationary slaughter of cattle in order to improve animal welfare and meat quality.

Methods

Slaughter plants

One mobile and one stationary slaughterhouse were studied. The mobile plant had capacity for about four animals per hour or 30-35 animals per day and the stationary plant about 45-50 animals per hour or 290-320 animals per day. The mobile plant included a cooling unit and staff spaces, all housed in two trucks with trailers (Figure 1).

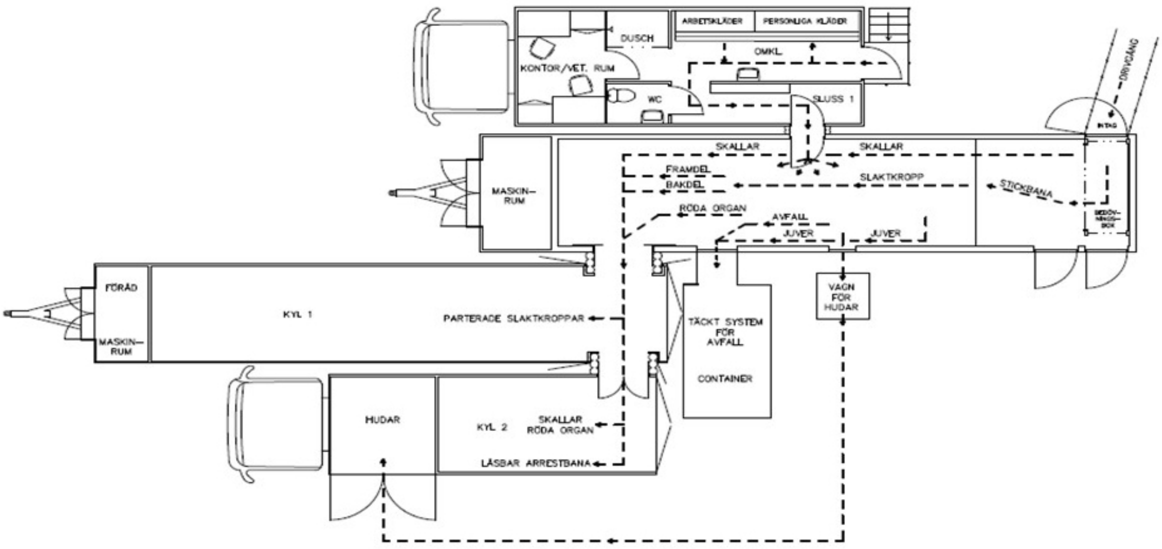

Figure 1. *Drawing of the mobile slaughter plant including staff spaces and cooling units, housed in two trucks with trailers. The slaughter unit itself was housed in one of the trailers, the second top section of the drawing. The animals were driven into the stun box, to the far right of the picture. The driveway was directed perpendicular to the plant so that the animals went straight into the stun box (the drawing is misleading).*

At the mobile plant, the animals were taken from the farm facilities (or, at one occasion, from pasture) to an inspection pen (Figure 2) where they were gathered in groups of up to about five animals. From the inspection pen, the animals were driven by the farm staff, the slaughterhouse staff or staff from both the farm and plant along the driveway to the stun box. The base of the driveway was the ground area outside the slaughterhouse. The driveway had walls of horizontal metal pipes and varied in length between 240 and 570 cm, average (±SD) 492 (±105) cm, depending on how the slaughterhouse was parked in relation to the farm buildings. The walls were sometimes covered by temporarily mounted boards. The driveway was limited by a sliding gate at the exit from the inspection pen and a guillotine gate at the entrance to the stun box (Figure 2-3). In addition, there was a sliding gate approximately halfway into the driveway. The floor of the stun box sloped slightly laterally and was covered with a rubber mat (Figure 3). The stunning operator stood on the right side of the animal. Halfway into the observation period, a modification of the stun box was carried out by installing a triangular plate (Figure 3) so that the animals could more easily fall out of the box after being stunned, and the chaining and hoisting could be performed faster and with less risks to the staff.

***Figure 2**. The inspection pen and the driveway to the stun box at the mobile plant.* (Photo: Anne Larsen, SLU)

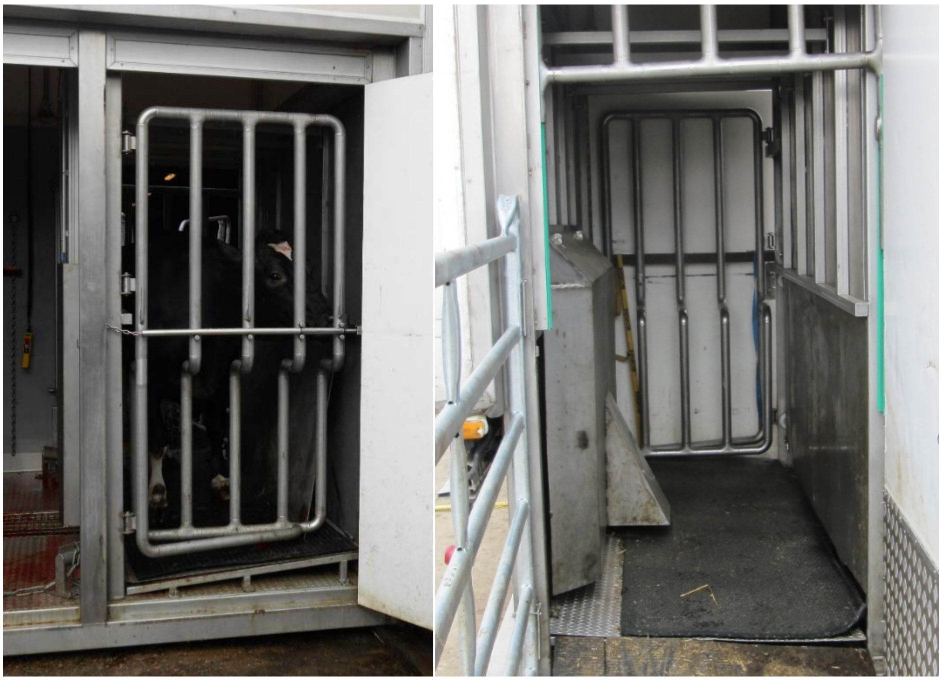

***Figure 3**. The stun box at the mobile plant, seen from the front (left) and from the entrance at the rear (right). To the left of the left-hand photo, the space for bleeding is seen, to which the front door was normally closed during slaughter (open in the photo). In the right-hand photo, the guillotine gate is seen at the top and the triangular plate installed during the observation period to facilitate the hoisting of the stunned animals. The animals fell from the shooting box to the right in the right-hand photo.* (Photo: Lotta Berg and Anne Larsen, SLU)

The animals slaughtered at the stationary plant were transported from the farm in the morning of the slaughter or the day before. In the former case they were kept for a shorter or longer period of time, with access to water. In the latter case, the animals were usually kept overnight in single boxes in the plant's raceway system, with access to feed and water. A smaller number were kept overnight in group boxes. At the time of slaughter, the animals were driven in the raceway system into the stun box. The part of the driveway observed was closest to the stun box, 725 cm long, and was limited by a guillotine gate both at the rear end and at the front at the entrance to the stun box. In addition, there was a guillotine gate in the middle of the driveway. The floor was made of rubber mats sprinkled with sawdust and the walls were all of dark colored plywood. The floor of the stun box leaned slightly laterally and was covered with a rubber mat. The walls were of building board or plain metal (Figure 4). The stunning operator stood on the left side of the animals.

Figure 4*. The stun box at the stationary slaughter plant, seen from behind. The guillotine gate at the entrance to the stun box is lifted. The animals fell from the shooting box to the right in the photo.* (Photo: Anne Larsen, SLU)

At both plants, a cartridge-driven penetrating bolt gun was used for stunning. At the mobile plant, ammunition Cash 25 was used and at the stationary plant Cash 22 or Cash 25. After stunning the animals were bled by thoracic sticking. The statutory standard routine for the mobile plant (last updated on April 10, 2017) stipulated that the time between stunning and bleeding ("sticking time") should be as short as possible, that the benchmark was a maximum of 120 seconds and that this time could be exceeded in single cases. The standard routine for the stationary plant (last updated July 15, 2015) stipulated that bleeding should begin within 60 seconds after stunning.

At the stationary plant, the carcasses were stimulated electrically with the aim of giving the meat better conditions for tendering. At both plants, seven days of hanging was applied from slaughter to cutting. The mobile plant suspended the half carcasses in the pelvis (Figure 5) immediately after slaughter, i.e. before cooling. Partitioning in quarters was done in connection with transfer from the mobile cooling unit to the hanging plant, after which the meat was usually hung as quarters for the rest of the time. In a few cases, the meat was hung as a loin for part of the time. At the stationary plant, the half carcasses were Achilles-hung until the loin was cut 1-2 days after slaughter and hung for another 5-6 days.

Figure 5. *Pelvic hanging of the carcass at the mobile slaughter plant.* (Photo: Karin Wallin, SLU)

Animals and data collection

Observations of mobile slaughter of 8-21 animals per day were performed on 17 days between 4 February 2016 and 16 March 2017, at 15 cattle farms in southern-central Sweden. Only animals delivered from the farm where the mobile plant was parked during slaughter were included in the project (thus excluding any animals that had been moved from a nearby farm on the same or the previous day).

Observations at stationary slaughter were performed on 17 days between April 13, 2016 and February 28, 2017, 10-25 animals per day from 144 farms (1-10 studied animals per farm).

Observations were made regarding:

- Animal handling in the driveway to the stun box (useful data from 596 animals).
- Animal behaviour in the driveway to the stun box and in the stun box (596 animals).
- Blood chemistry at bleeding (samples from 571-594 animals).
- Carcass characteristics immediately after slaughter (591 animals).
- Veterinary inspection findings (596 animals).
- Meat quality characteristics in the sirloin after 7 days of hanging (samples from 546 animals, 378-543 animals analysed).
- Events that might have affected the slaughter process.

Two research technicians (A and B) performed all observations and communicated with each other via walkie talkie to ensure that the same animals were observed. Technician A was placed by the driveway (outside of the mobile plant) observing weather, animal management, animal behaviour and times in driveway and stun box (Figure 6), while technician B was placed at the stun box or bleeding site (inside the mobile plant) observing animal behaviour in the stun box, shooting, bleeding, times in the stun box and until sticking, and carcass qualities, as well as collecting blood samples and analysing blood lactate.

Figure 6*. A research technician observed animal handling and behaviour in the inspection pen and the driveway to the stun box at the mobile plant.* (Photo: Karin Wallin, SLU)

At the time of slaughter, as many animals were observed as practically possible. This meant that all actions with an animal had to be completed by technician B before observations of another animal were initiated by technician A. At that time, the first animal available was chosen. The selection of animals was regarded as random. The procedure meant that a large number of animals were slaughtered without being observed, especially at the stationary plant.

At the mobile plant it was noted whether farm staff, plant staff or both handled the animals in the driveway. At the stationary plant, information was obtained from the slaughterhouse management about the delivery farm identity, the transport distance from the farm to the plant, and whether or not the animals had stayed in overnight lairage at the plant.

For each animal, the number of the following stockperson actions were observed:

- Touched hind part of the animal lightly (behind withers).
- Touched front part of the animal lightly (in front of withers).
- Patted hind part of the animal (behind withers, arm bent in wrist or elbow, but not in shoulder).
- Patted front part of animal (in front of withers, arm bent in wrist or elbow, but not in shoulder).
- Hit hind part of the animal (behind withers, arm lifted in shoulder).
- Hit front part of the animal (in front of withers, arm lifted in shoulder).
- Pulled the animal (any part of the body).
- Pushed the animal.
- Prodded the animal with a sharp object.
- Restrained the animal (any part of the body).
- Twisted tail of animal.
- Waved arm or object.
- Kicked the animal (on any body part).
- Hit the animal with a gate (from side or top).

- Applied an electric goad to hind part of the animal.
- Spoke, shouted or whistled.
- Hit interior with hand or tool.

For all actions, it was noted whether it was performed with the hand (body) or with a tool. There were a total of eight different stockpersons at the mobile plant and six at the stationary plant, overall at all slaughter occasions.

Animal behaviour was observed directly in the driveway of technician A and the stun box of A (mobile plant) or B (stationary plant). Technician A noted whether an animal appeared to be particularly hesitant or nervous before driving began. For each animal, the number of the following stress-related behaviours was observed:

- Moved backwards (at least two steps).
- Ran (moved quickly in trot or gallop).
- Tripped without moving forward.
- Turned around or tried to turn around (head bent backwards).
- Slipped slightly (continued walking without noticeable rest, only claws and lower legs touched ground).
- Slipped severely (out of rhythm, lowered body but only claws and lower legs touched ground).
- Fell (body touched ground).
- Kicked (towards stockperson, other animal or interior).
- Charged (towards stockperson, other animal or interior).
- Fought violently (threw itself against interior, possibly exhibited panting, trembling or frothing).
- Froze (stood still).
- Vocalised.
- Defecated or urinated.

In addition, the number of times the animal exhibited explorative behaviour (sniffed or looked around) was observed.

The time for different operations was directly monitored by both A and B using wristwatches that were synchronised before each slaughter occasion. For each animal, observations were made of the time in the driveway, the time in the stun box until first shot, and the time from the last shot to sticking (sticking time). In cases where re-shooting was done, the number of shots was noted.

Blood samples were taken from all animals in connection with bleeding. Lactate was analysed directly with a portable meter (Lactate Plus, Nova Biomedical Corp., Waltham, Massachusetts, USA). A small amount of blood was collected in a plastic spoon into which the test strip was immersed directly after sticking. The remaining blood samples were centrifuged for 30–60 minutes, serum was refrigerated for a maximum of 48 hours and then frozen at -18–-23 ˚C for later analysis at the University Animal Hospital's clinical-chemical laboratory, SLU, Uppsala. Glucose was analysed with Architect c4000 (Abbott Laboratories, Chicago, Illinois, USA) and cortisol was analysed with Immulite 2000 (Siemens Healthcare Diagnostics, Erlangen, Germany).

For each animal, the carcass was graded by the slaughterhouse staff with respect to conformation and fat and these data were recorded on a continuous basis. The graders had received special education, were trained annually and held a certificate of competence issued by the Swedish Board of Agriculture which conducted audits approximately every two months to ensure uniform and correct classification. The carcass was graded according to an system common to the European Union (EUROP) in five main classes:

- P. Poor.
- O. Fair.
- R. Good.
- U. Very good.
- E. Excellent.

Each main class was subdivided using – (low) or + (high), resulting in totally 15 classes from P– (coded as 1) to E+ (coded as 15).

Fat was graded according to a Swedish system in five main classes:

1. Very low.
2. Low.
3. Average.
4. High.
5. Very high.

Each main class was subdivided using – (low) or + (high), resulting in totally 15 classes from 1– (coded as 1) to 5+ (coded as 15).

The slaughterhouse staff also graded each animal with regard to manure contamination on critical skin areas (the lower abdomen, the lower chest, the hock, the Achilles tendon, the carpus, the lower neck, the genitals and udder, and the area around the anus). The graduation was carried out according to a system agreed by the Swedish Meat Industry Association in four classes:

0. No or very slight contamination.
1. Moderate contamination with significant occurrence of manure.
2. Severe contamination or dry manure lumps.
3. Very severe contamination or extensive dry manure lumps and/or skin burns.

The carcass and organs of each animal were inspected by official veterinarians or auxiliaries from the National Food Agency and information on inspection findings was obtained from the veterinarians. The inspection was regulated by legislation and included 37 disease codes (of which about 32 applied to cattle).

In connection with the cutting 7 days after slaughter, the meat marbling (amount of intramuscular fat) in a cut of *M. longissimus dorsi* between the 10th and 11th ribs) was graded by the slaughterhouse staff according to a five-level scale from 1 (not marbled) to 5 (very well marbled) by comparison with standard photos from the USDA scale.

At cutting, the final pH of the meat was measured with Testo 205 (Nordtec Instrument AB, Gothenburg) (Figure 7) and a 15-20 cm long piece of *M. longissimus dorsi* closest to the entrecote was extracted, vacuum packed and frozen in -20–-25 ˚C immediately after finishing cutting. The size of the meat samples varied according to the type of animal, with a mean weight (±SD) of 1481 (±381) grams.

***Figure 7**. Measuring meat pH at cutting seven days after mobile slaughter.*
(Photo: Karin Wallin, SLU)

The meat samples were analysed after 43-398 (mean 251) days at a laboratory (SP Food and Bioscience, later RISE Research Institutes of Sweden) for weight loss at thawing, weight loss at cooking, pH and colour of thawed raw meat, and texture of cooked meat. The meat was thawed in the vacuum pack at 4-5 ˚C for 24 hours, after which an approximately 1 cm thick slice weighing 100 grams was cut out and stored at 20 ˚C for later analysis of fat content. Two to three further 5 cm thick slices were cut, weighed, vacuum packed and tempered in water bath to 20 ˚C core temperature ("thawing"), which was reached after about 2 hours. The pieces were weighed and the percentage weight loss at thawing was calculated.

The colour of the meat was measured at 4-10 spots without visible fat on one of the thawed pieces using a system consisting of a digital camera (Nikon D90, Nikon Corp., Tokyo, Japan), a constant light test chamber and image analysis software (DigiEye v2 .53c, VeriVide Ltd., Enderby, UK). The colour was described according to the CIELAB system (CIE, 2004a, b) in three dimensions representing brightness (L*, from 0=black to100=white), redness (a*, from negative=green to positive=red) and yellowness b*, from negative=blue to positive=yellow). Meat pH was measured with Testo 205 (Nordtec Instrument AB, Gothenburg) on the surface of the pieces. The pieces were then vacuum-packed and heated in 75 ˚C water bath to the core temperature 69 ˚C ("cooking"), cooled under running water and placed at 4–5 ˚C for 16 hours, after which the test pieces were removed from the vacuum package, weighed and the percentage weight loss at cooking was calculated.

Thereafter as many test pieces as possible were punched out for measuring meat texture. Texture ("tenderness") was measured as Warner-Bratzler shear force (Bourne, 2002) and as compressive load according to the compression method (Bourne, 2002), both analysed with Instron 5542 (Instron Ltd., High Wycombe, UK). The measurements of shear force were performed on approximately 4–10 cylindrical specimens, 15 mm in diameter, stamped in the direction of the muscle fibres. The cutting blade was 1 mm thick and moved downwards at a speed of 50 mm/min. The measured cutting resistance indicates the maximum force required to cut the meat, expressed in N.

Compression measurements were carried out on approximately 4-10 cylindrical specimens, 15 mm in diameter and 15±3 mm high, punched perpendicular to the muscle fibres. The compression therefore occurred in parallel with the fibre direction. The instrument was equipped with a 60 mm diameter plate moving downwards at a speed of 50 mm/min, thereby compressing the test piece. The compressive load at 40% measured the maximum pressure required to compress the sample 40% (i.e. to 60% of its original height), expressed in MPa.

The raw fat content of the meat was analysed by Eurofins Food & Feed Testing Sweden according to Schmid-Bondzynski-Ratzlaff (NMKL NordVal International, 1989).

Statistical analysis

Data were collected in Excel 2013 (Microsoft, Redmond, Washington, USA). For statistical processing, Stata/IC 13 (StataCorp, College Station, Texas, USA) was used. All analyses was performed with the animal as the unit of analysis. Background variables were constructed, representing slaughter plant (mobile or stationary), slaughter site (15 sites for mobile slaughter; 1 site for stationary slaughter), farm of origin (159 farms), season (spring, summer, autumn or winter), transport distance from farm to stationary plant, overnight lairage at stationary plant (no or yes), cloudiness outside the mobile plant (clear, clouds or overcast), precipitation (rainfall or snowfall) outside the mobile plant (no or yes), wind outside the mobile plant (weak or strong), whether last animal in inspection pen (no or yes), hour when driving began, outdoor air temperature in driveway, outdoor relative air humidity in driveway, hour when entering stun box, hour for sticking, staff driving animals at mobile plant (farm, plant or both), animal breed type (beef or dairy), slaughter animal category (bull, steer, cow or heifer), animal age, horned (no or yes), emotional expression when leaving inspection pen (normal, hesitant or nervous), slaughter weight, meat temperature at cutting, and meat marbling (degree 1–5).

Outcome variables representing animal handling included number of driving actions using hand (the sum of all types of driving actions), number of driving actions using tool, inappropriate driving action (i.e. twists tail or hits with gate one or several times, or hits with hand/tool more than five times or uses an electric goad more than five times; no or yes), no active driving at all (no or yes), time in driveway, time in stun box until first shot, time from last shot to stickning, and number of shots. Outcome variables representing animal behaviour included number of stress-related behaviours (the sum of all types of stress-related behaviours) in driveway and in stun box, more than three stress-related behaviours in driveway and more than one such behaviour in stun box, clear stress-related behaviour in driveway and stun box (i.e. falls, turns or fights violently one or more times; or trips, runs, jumps, slips, kicks, charges, freezes, vocalises or defecates/urinates more than five times; no or yes), and no stress-related behaviour at all in driveway and in stun box (no or yes). Outcome variables representing blood chemistry included blood cortisol, blood glucose, blood lactate, and one or more high blood value (above third quartile). Outcome variables representing carcass qualities included fecal contamination (degree 0-3), carcass conformation (grade P- to E+), carcass fat (grade 1- to 5+), and time from stunning to cooling. Outcome variables representing meat quality included lightness, redness, yellowness, pH at cutting (final pH), high pH at cutting (above 5.8), weight loss at thawing, weight loss at cooking, texture expressed as shear force, texture expressed compressive load, and raw fat content.

The data included 40 beef-dairy crossbred animals which were coded as dairy type in the analysis. There were two older bulls which, together with young bulls, were coded as bulls. For a number of continuous background variables, corresponding new ordinal variables were constructed with five equally large categories. The animal's emotional expression when the driving began was only noted when it was obviously hesitant or nervous (the rest were coded as normal). Whether an animal was left alone in the inspection site at the mobile plant was also noted only for some of the animals (the rest were coded as not alone).

For continuous variables, the number of animal observations, median, interquartile range, mean and standard deviation were calculated. For categorical background variables, the number and percentage of animals per category were calculated, when relevant dividing further into categories of one or two additional categorical background variables. Diagrams were used to illustrate simple relationships between the variables, in most cases also differences between the two plants.

Multivariable statistical models were constructed for the number of stress behaviours in the driveway and stun box, the risk of a large number of stress-related behaviours in the driveway and stun box, the risk of a clear stress-related behaviour in the driveway and stun box, blood cortisol, blood glucose, blood lactate, risk of at least one high blood value, conformation class, fat class, risk of a final meat pH higher than 5.8, weight loss at thawing and cooking, as well as meat texture expressed as shear force and compressive load. The model type was adapted to the outcome variable and only background variables (and first-order interaction effects) that contributed to the models in a meaningful manner were included. The categorical counterparts to continuous variables were used to reveal nonlinear relationships.

Slaughter plant identity was forced into all models as an independent variable. In addition, background variables representing season, driving hour (if relevant, replaced by box hour or stick hour), breed type, slaughter animal category, age and slaughter weight were tested for inclusion. However, in the models of conformation and fat, only seasonal and animal-based background variables were tested (season, breed type, slaughter animal category, age and slaughter weight). In all multivariable models, farm identity was included as a random effect to adjust for clustering by farm.

Additionally, for certain outcome variables, separate models for the mobile and stationary plant subsets were constructed, adding independent variables relevant to the respective plant. Thus, in addition to the common background variables, cloudiness, wind, precipitation, outdoor air temperature and driving staff were tested in the models of the mobile plant subset, and transport distance and overnight lairage in the the models of the stationary plant subset.

The validity of the models was checked using Pregibon's link test (Pregibon, 1980) and inspection of residuals. Diagrams were used to illustrate the effect of different background variables (marginal mean values with confidence intervals). In view of the large number of tests, a 1% significance level was used. The proportion of the variation in the outcome variables attributable to differences between the farms was estimated by calculating the intra-class correlation coefficient.

Linear relationships between selected continuous and ordinary variables were also investigated using correlation (Pearson or Spearman), but without regard to clustering.

Results

Background factors

The conditions of the farms that delivered to the mobile plant varied greatly in terms of the possibilities and efforts to handle the animals in a good way. To some extent, the animal material also varied by the fact that some farms, for example, had more dairy steers while other farms mainly supplied beef bulls. The percentage of horned animals was 6.7%. At the stationary plant, 32% of the animals stayed overnight before slaughter. At the mobile plant, 32% of the animals remained alone in the inspection pen before being driven. Power cuts or technical hassle concerning e.g. the bolt gun, hide remover, cleavage saw or computer equipment occurred during the slaughter of ten animals at the mobile plant and three animals at the stationary plant. Table 1 shows descriptive statistics of continuous background variables for both slaughter plants.

***Table 1**. Overall descriptive statistics of continuous background variables.*

Variable	Number of observations	Median	Interquartile range	Mean	SD
Air temperature, ˚C	596	9.4	12.1	10.98	7.69
Air rel. humidity, %	547	86	17	83.85	13.11
Age, months	591	24	15	31.85	24.81
Slaughter weight, kg	591	339	65.2	344	57.45
Transport distance[1], km	298	96.2	85.3	98.97	57.95

[1] Only at the stationary plant.

The animals were transported up to 250 km to the stationary plant and the animals that stayed overnight at the plant had on average been transported about 50 km longer than those that did not stay overnight.

The distribution of animals across seasons was similar at the two plants. The stationary slaughter took place slightly earlier in the day. As expected, the variation within and between seasons in terms of air temperature and humidity in the driveway was significantly greater at the mobile plant. Outside the mobile plant weather conditions were varied. For most animals, the weather was clear. The wind was strong when driving 19% of the animals, and rainfall or rainfall precipitation occurred in 11% of the cases.

The animal material differed slightly between the plants; the mobile plant had a larger proportion of beef-type animals and a smaller proportion of cows than other slaughter animal categories. The age of different slaughter animal categories was similar at the two plants, although the cows were slightly older at the mobile plant than the stationary. The proportion of bulls was largest in the summer, while it was a bit more common with heifers in autumn and cows during the winter, which was reflected in the age of animals at different seasons. Animals slaughtered during the summer were therefore on average 11-16 months younger than in other seasons. At the mobile plant, 66.8% of the animals were driven by the farm staff, 8.4% of the plant staff and 24.8% of both together. At the mobile plant, 6.7% of the animals were obviously hesitant or nervous when the driving began, while this was almost not found at all at the stationary plant.

The slaughter weights were similar at the two plants for bulls, steers and heifers, but slightly higher for the cows at the mobile plant than at the stationary one. There was no clear relationship between slaughter weight and transport distance or overnight lairage at the stationary plant. The meat temperature at cutting (which probably reflects the temperature of the cooling unit) was substantially lower at the mobile plant.

At the mobile plant, more animals had a high degree of meat marbling, especially dairy animals, as well as steers and cows. The fat content of the meat was slightly higher at the mobile plant, and in particular in dairy cattle, as well as in steers and cows. There was a tendency for increasing fat content with increasing age. At the mobile plant, the fat content decreased with higher conformation, which was not the case at the stationary plant where there was a maximum at moderately high conformation classes. In both plants, the meat fat content increased with a higher fat class and more marbling.

Animal handling

The farm stockpersons' involvement in driving the animals and ways of handling the animals was observed to vary between farms. Table 2 shows descriptive statistics for continuous results variables representing animal management at both slaughter plants.

Table 2*. Overall descriptive statistics of continuous outcome variables representing animal handling.*

Variable	Number of observations	Median	Interquartile range	Mean	SD
No. of active driving actions with hand	596	1	6	6.31	15.1
No. of active driving actions with tool	596	3	12	10.3	18.5
No. of active driving actions with hand or tool	596	7	16	16.6	26.5
Time in driveway, minutes	595	1.93	2.77	3.10	3.91
Time in stun box until first shot, seconds	595	28	24	35.7	26.5
Time from last shot to sticking, seconds	595	60	54	72.8	36.4

The number of manually driven animals was slightly higher at the mobile plant, while the number of active driving actions per animal with a tool was higher at the stationary plant. The differences remained when calculating the number of driving actions per minute. The distribution of the number of driving actions per animal was very skewed by the fact that the vast majority of animals were driven actively a few times and only a few received a large number of actions. Single animals at the mobile plant received about 140-220 actions. In both plants, touching and patting were the most common ways to drive the animals by hand and patting the most common way when using a tool. At the stationary plant, a paddle was the dominant driving tool, while plastic pipes also occurred to some extent at the mobile plant. Four of the animals at the mobile plant were driven into the stun box, after which they got out of the box and had to be re-entered. One animal at each plant was pulled into the stun box with a winch. The method of handling the animals also varied between different stockpersons at the plants.

The percentage of animals driven inappropriately was 24% on mobile and 6.7% at the stationary plant. This percentage was 17% in the animals that exhibited backwards movement compared with 9.9% in animals that did not, and 16% in animals that turned around during driving compared with 15% in non-turning animals. The number of driving actions was higher in animals that were driven in an inappropriate manner. The percentage of animals not driven at all was 15% on mobile and 3.7% at the stationary plant. This percentage was 6.2% in animals that moved backwards compared to 20% in animals that did not, and 6.0% in animals that turned around during driving, compared with 11% in non-turning animals.

At the stationary plant, the number of drives decreased with the transport distance in animals that stayed in overnight lairage, but not as clearly in animals that did not stay overnight. On average, there was no clear connection between overnight stay and the number of driving actions, although animals that did not stay overnight were driven the most times. The proportion of animals driven inappropriately increased with the transport distance while the proportion of animals not driven at all decreased. Among the overnight animals, 11% were driven inappropriately, while the corresponding percentage for non-overnight animals was 4.5%. The percentage of animals not driven at all was approximately equal between those that stayed overnight (4.2%) and those that did not (3.5%).

The driving time was extremely skewed; most animals had a short driving time and only a few very long. The average driving time was slightly longer at the stationary plant, but cows had longer driving times at the mobile plant where single cows spent 25-38 minutes in the driveway. At the mobile plant, animals judged to be hesitant at the start of driving and animals that remained alone in the inspection pen had slightly longer driving times than other animals. The average driving time at the mobile plant was slightly longer when the plant staff drove, but single animals driven by farm staff had the longest driving times. The driving time was longer in animals that moved backwards or turned around in the driveway, as well as in animals showing explorative behaviour. There was no clear connection between driving time and transport distance or overnight lairage at the stationary plant.

The time in the stun box until first shot was also extremely skewed. The average box time was approximately equal at the two plants, but a bull at the stationary plant was left for 5 minutes in the stun box before it was shot. The box times differed only marginally between slaughter animal categories. The differences in box time between animals with different slaughter weights were also marginal. At the mobile plant, animals that were considered nervous before driving had slightly longer box times than other animals. There was no clear connection between the box time and the transport distance or overnight lairage.

The percentage of animals shot more than once was 10% at the mobile and 2.7% at the stationary plant. At the mobile plant, shooting of single animals occurred up to five times, while at the stationary plant up to three times. In one of the cases at the mobile plant, the fourth and fifth shot were only given after sticking. Four of the animals at the mobile plant were shot while standing backwards in the stun box, either after having turned around in the box or after having entered it backwards.

The sticking times differed greatly between the plants and were considerably longer at the mobile plant, where the variation was also greater and single cows had sticking times of 230-270 seconds. At the mobile plant, the variation in sticking time increased slightly with slaughter weight, which was not the case at the stationary plant. At the mobile plant, animals considered to be nervous before being driven had on average slightly longer sticking times than other animals. At the mobile plant, the average (±SD) sticking time was 100 (±27) seconds prior to rebuilding of the stun box, compared to 106 (±35) seconds after the rebuilding, and the longest sticking times occurred after the change. There was no clear connection between the sticking time and the transport distance to the stationary plant. On the other hand, the sticking time was much shorter in animals that had stayed overnight. An incorrect position in the stun box after shooting resulting in obstructed chaining and hoisting was observed in 14 animals at the mobile plant, but for only one animal at the stationary. One of the animals at the stationary plant was bled while lying in the stun box.

Animal behaviour

Animal behaviour was observed to vary between farms, as the animals appeared to be more calm at some farms while they were more upset and angry at others. Table 3 shows descriptive statistics for continuous performance variables relating to animal behaviour at both slaughter plants.

Table 3. *Overall descriptive statistics of continuous outcome variables representing animal behaviour*.

Variable	Number of observations	Median	Interquartile range	Mean	SD
No. of stress-related behaviours in driveway	596	4	7	5.81	6.61
No. of stress-related behaviours in stun box	595	2	3	2.73	3.19
No. of stress-related behaviours in driveway or stun box	595	7	9	8.50	7.28

On average, the number of stress-related behaviours of the animals in the driveway was slightly higher at the stationary plant. The pattern was maintained when the comparison was based on number of behaviours per minute. The most common behaviour was moving backwards, followed by turning around, as well as defecation/urination on the mobile and vocalisation at the stationary plant. The percentage of animals showing more than three stress behaviours in the driveway was 46% at the mobile and 61% at the stationary plant. The percentage of animals showing more than one stress behaviour in the stun box was 50% at the mobile and 56% at the stationary plant. The percentage of animals showing clear stress behaviour in the driveway or stun box was 65% at the mobile and 70% at the stationary plant. The percentage of animals that did not show any stress behaviour at all was 3.4% at both plants. At the mobile plant, it was noted that strong sounds from inside the slaughter unit (saw noise, cries from the staff) occasionally disturbed animals on the outside, thereby complicating driving to the stun box.

It was not possible to demonstrate a significant association between any of the background variables and the number of stress behaviours in the driveway in the multivariable models based on the data from both plants or only the stationary plant. According to the model based solely on data from the mobile plant, dairy-type animals can be expected to have 0.69 more such stress behaviours than beef animals (p=0.0053). In the spring, steers are also expected to have 2.4 fewer stress behaviours than bulls (p<0.0001) and 2.2 fewer than heifers (p=0.0017), but not during other seasons.

There was no significant association between any of the background variables and the risk of more than three stressful behaviours in the driveway in the multivariable models. According to the model based on data from both plants, 29% of the total variation in the risk of more than three stress behaviours in the driveway could be attributed to differences between farms. In the model based on the mobile plant alone this percentage was higher (44%), and in the model based on the stationary plant it was lower (5.9%).

There was no significant association between any of the background variables and the risk of clear stress behaviour in a multivariable model based on the data from both plants or only data from the mobile plant. According to the model based on only the stationary plant, steers are expected to have 1.5 times lower odds for clear stress behaviour than cows (p=0.0039) and 1.5 times lower odds than heifers (p=0.0069) (Figure 8). According to the model based on data from both plants, 20% of the total variation in the risk of clear stress behaviour in driveway can be attributed to differences between farms. In the model based on data from the mobile plant alone this percentage was higher (32%), and in the model based on the stationary plant it was lower (9.8%).

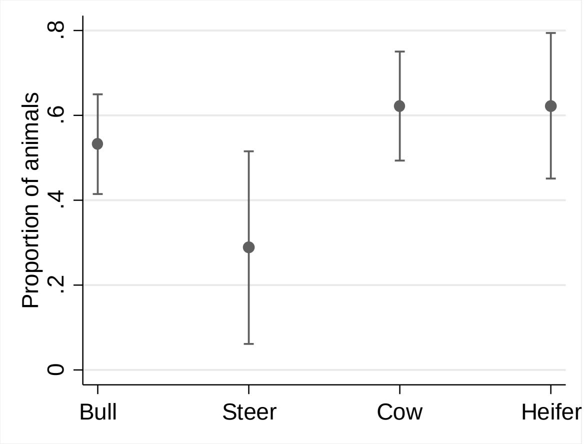

Figure 8*. Estimated marginal means of the proportion of animals displaying clear stress behaviour in the driveway for different slaughter animal categories, according to a multivariable statistical model based on data from the stationary slaughter plant alone. The bars are 99% confidence intervals.*

On average, the number of stress behaviours in the stun box was slightly higher at the stationary plant and the pattern remained when comparing the number of behaviours per minute. At both plants, the most common behaviours were slipping, turning and moving backwards.

According to a multivariable model based on the data from all studied animals, cows at the mobile plant are expected to have 0.90 times fewer stress behaviours in the stun box than cows at the stationary plant (p=0.0027). According to a model based solely on data from the mobile plant, heifers can be expected to show 0.53 more stress behaviours than steers (p=0.0075) (Figure 9). There was no significant relationship between any of the background variables and the number of stress behaviours in the model based solely on data from the stationary plant.

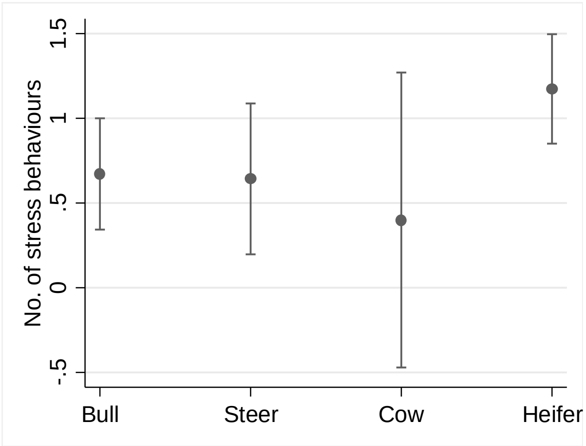

Figure 9. *Estimated marginal means of the number of stress-related animal behaviours in the stun box for different slaughter animal categories, according to a multivariable statistical model based on data from the mobile slaughter plant alone. The bars are 99% confidence intervals.*

There was no significant relationship between any of the background variables and more than one stress behaviour in the stun box in a multivariable model based on the entire data material or only data from the mobile plant. According to the model based only on data from the stationary plant, the odds of more than one stress behaviour in the stun box in the spring is expected to be 1.13 times lower than in summer (p=0.0052), 1.67 times lower than in autumn (p=0.0010) and 1.18 times lower than in winter (p=0.0034) (Figure 10). According to a model based on data from both plants, 7.1% of the total variation in the risk of more than one stress behaviour in the stun box can be attributed to differences between farms. In the model based on the data from the mobile plant this percentage was slightly lower (4.7%), and in the model based on the data from the stationary plant somewhat higher (10.7%).

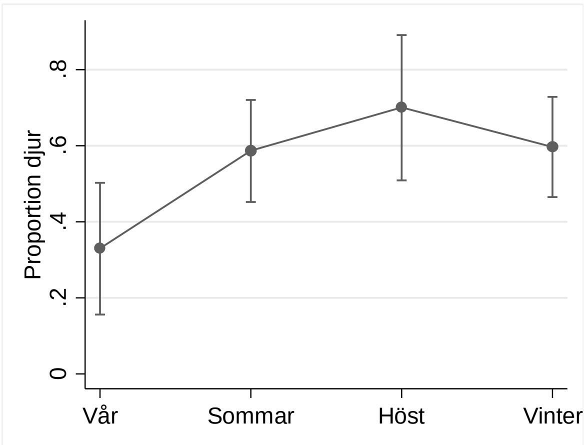

Figure 10. *Estimated marginal means of the proportion of animals with more than one stress-related behaviour in the stun box for different seasons, according to a multivariable statistical*

model based on data from the stationary slaughter plant alone. The bars are 99% confidence intervals.

According to a multivariable model based on the entire data, the odds of clear stress behaviour in the stun box is expected to be 1.3 times lower at the stationary plant than at the mobile one (p=0.0056) at slaughter weights below 302 kg but not at higher slaughter weights. According to the same model, the odds of such behaviour in animals between 22 and 26 months slaughtered between 9 and 11 am are expected to be 2.2 times lower than before 9 am (p=0.0008) and 2.6 times lower than after 1 pm (p=0.0023), but the same difference between slaughter hours did not exist at other ages. Finally, heifers are expected to have 1.3 times higher odds for clear stress behaviour than steers (p=0.0004) (Figure 11). There was no significant relationship between any of the background variables and clear stress behaviour in the stun box in models based solely on data from the mobile or stationary plant alone. According to the model based on data from both plants, 9.1% of the total variation in the risk of clear stress behaviour in the stun box can be attributed to differences between different farms. In the model based on data from the mobile plant alone this percentage was slightly lower (7.7%), and in the model based on the stationary plant somewhat higher (14%).

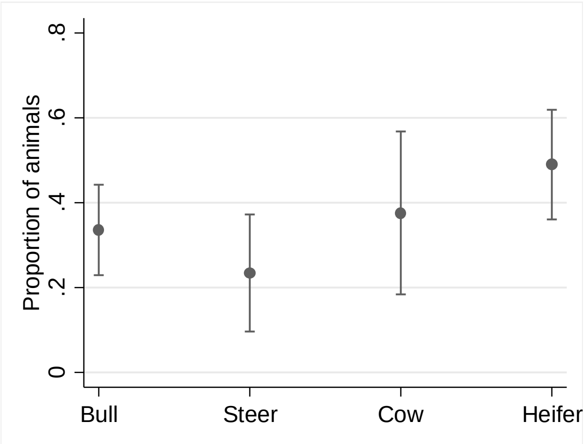

***Figure 11**. Estimated marginal means of the proportion of animals with clear stress behaviour in the stun box for different slaughter animal categories, according to a multivariable statistical model based on data from both slaughter plants. The bars are 99% confidence intervals.*

On average, the total number of stress behaviours in the driveway and stun box was slightly higher at the stationary plant. At both plants, the most common animal behaviour was moving backwards, followed by turning around. However, the behaviour that single animals showed the most times was vocalising. Cows at the mobile plant showed the most explorative behaviours, but otherwise the differences between plants and slaughter animal categories were small. Up to seven explorative behaviours were displayed in the stun box. On average, the number of stress behaviours was slightly higher for bulls and cows than for steers and heifers, at both plants. The emotional expressions of the animal before driving had no clear relationship with the total number of stress behaviours. At the mobile plant, the total number of stress behaviours was slightly higher in animals that were driven in an inappropriate way and lower in animals not driven actively at all, while the relationships were almost reversed at the stationary plant.

Most animals exhibited at least one explorative behaviour in the driveway or stun box and only 7.4% showed no such behaviour. Animals exhibiting explorative behaviour simultaneously showed several stress behaviours and more often clear stress behaviour, backward moving and turning around. They were also driven actively several times and more often in an inappropriate manner.

There was no clear association between the total number of stress behaviours and transport distances or overnight lairage. With greater transport distances, the proportion of animals showing clear stress behaviour decreased, while the proportion of animals that did not show any stress behaviour increased. The percentage of animals with clear stress behaviour was slightly higher in animals that stayed overnight (76%) than in those who did not (67%). The percentage of animals that did not show any stress behaviour at all at the same time was lower among those who stayed overnight (2.1%) than among those who did not (4.0%). There was a significant correlation between the number of driving actions and the number of stress-related behaviours in the driveway of the mobile plant (Spearman rho=0.45; $p<0.0001$).

Blood chemistry

Table 4 shows descriptive statistics for continuous outcome variables regarding blood chemistry at both slaughter plants.

Table 4*. Overall descriptive statistics of continuous outcome variables representing blood chemistry.*

Variable	Number of observations	Median	Interquartile range	Mean	SD
Cortisol, nmol/L	571	65.7	74.2	74.4	50.5
Glucose, mmol/L	571	5.2	1.2	5.57	1.54
Lactate, mmol/L	594	4.65	2.8	5.25	2.68

Blood cortisol levels were somewhat higher at the stationary plant and bulls had somewhat lower levels than other slaughter animal categories. At the mobile plant, animals that were perceived as hesitant when the observations in the driveway started had higher cortisol levels. There was a tendency for lower cortisol levels in animals transported longer and in animals not staying overnight at the stationary plant.

Regarding glucose levels, there were no clear differences between slaughter plants or different slaughter animal categories. At the mobile plant, animals that were perceived as hesitant or nervous had higher glucose levels. At the stationary plant there was no clear relationship between glucose levels and transport distance or overnight lairage.

Lactate levels were lower at the stationary plant but did not differ significantly between different slaughter animal categories. Hesitant or nervous animals at the mobile plant had higher lactate levels. There was a slight tendency for lower lactate levels in animals transported longer and subsequently not being lairaged overnight, but not in animals that did stay overnight. On average, however, the lactate levels were slightly lower in animals staying overnight.

Blood values were weakly to moderately correlated with each other (Spearman rho=0.21 between cortisol and glucose, 0.22 between cortisol and lactate and 0.36 between glucose and lactate, in all cases with p <0.0001). The percentage of animals with at least one high blood value was 51% at both plants.

According to the multivariable model of blood cortisol, significant differences between different types of slaughter animals are expected in some seasons, as well as significantly higher values in beef-type animals than in dairy animals. According to the blood glucose model, one can expect 1.1 times higher values in winter than in spring (p=0.0005). According to the model of blood lactate, 1.2 times higher values are expected at the mobile plant than at the stationary one (p=0.0068). According to the model, 32% of the total variation in blood cortisol can be attributed to differences between farms. The corresponding percentages for blood glucose and lactate were 14 and 32%, respectively.

According to the multivariable model, the odds of one or more high blood value in the spring is 1.1 times lower than in summer (p=0.0015) and 1.01 times lower than in winter (p=0.0018) (Figure 12). According to the same model, one can also expect the odds of bulls to be 1.2 times lower than in cows (p=0.0031) and 1.3 times lower than in heifers (p=0.0063) (Figure 12). Thirteen percent of the total variation in the risk of one or more high blood values may be attributed to differences between farms.

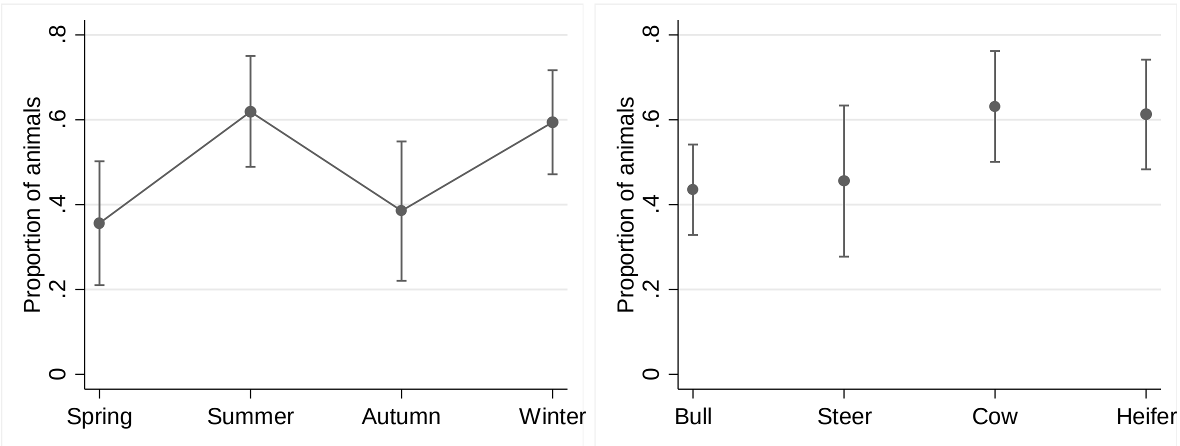

Figure 12*. Estimated marginal means of the proportion of animals with one or more high blood level of cortisol, glucose or lactate for different seasons (left) and different slaughter animal categories (right), according to a multivariable statistical model. The bars are 99% confidence intervals.*

Carcass qualities and veterinary inspection findings

At the mobile slaughter plant, the proportion of animals contaminated with manure was slightly larger. The animals at the mobile plant had a significantly higher conformations class. At both plants, beef-type animals were graded higher for conformation than dairy animals. Bulls were graded higher and cows lower than steers and heifers. At the mobile plant, bulls had a lower fat class than other slaughter animal categories. Other differences in fat class between plants and slaughter animal categories were not clear. The variables for form class and fat class were weak but clearly significantly correlated with each other (Pearson r=0.16; p=0.0001).

At the mobile plant, parasitic liver injury and ‘other pneumonia’ were significantly more frequent inspection findings than at the stationary plant. At the stationary plant, older mechanical injury was a comparatively common finding. Other inspection findings were relatively similar at the two plantss. No recent mechanical injury was noted. The time from sticking to cooling of the carcass was on average longer and more variable at the mobile plant. At the most, however, it was 2.5 hours at the mobile plant and 3.3 hours at the stationary one.

According to the multivariable model, the conformation class is expected to be 1.8 degrees higher at the mobile than at the stationary plant ($p<0.0001$). The marginal means (with 99% confidence interval) were 8.3 (7.6 to 9.1) and 6.6 (6.3 to 6.9) degrees, which on the EUROP scale corresponds to R (R to R +) and R- (O + to R-). Beef animals can be expected to have between 1.4 and 3.0 degrees (depending on the slaughter animal category) higher grading than dairy animals ($p<0.0001$) (Figure 13). The conformation class can also be expected to increase significantly with slaughter weight (Figure 13). According to the model, 72% of the total variation in conformation class could be attributed to differences between farms.

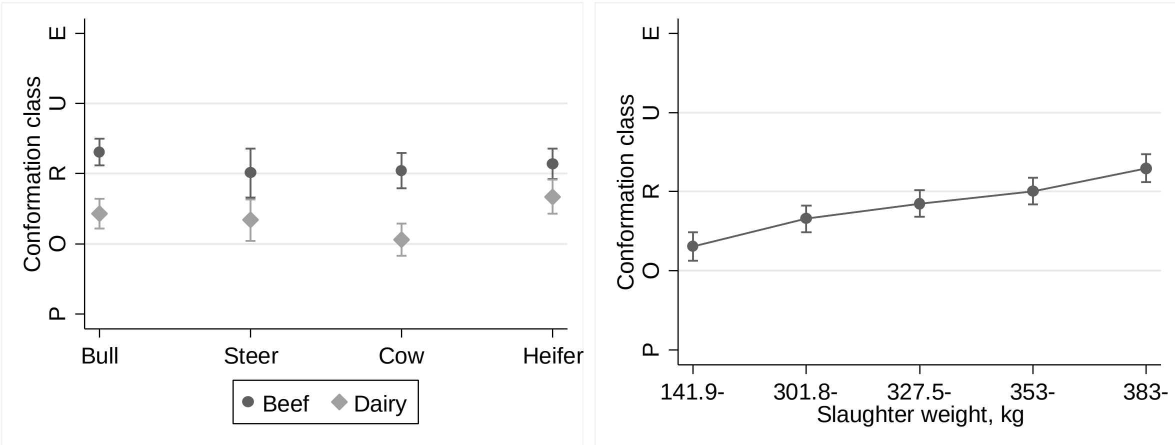

Figure 13. *Marginal means of conformation class for beef- and dairy-type animals of different categories (left) and for different slaughter weights (right), according to a multivariable statistical model. Class is indicated on the original EUROP scale. The bars are 99% confidence intervals.*

According to the multivariable model of fat class, there is a complex interaction between season, breed type, slaughter animal category and slaughter weight. The fat class is in most cases expected to increase with the slaughter weight (Figure 14). According to the model, 62% of the total variation in fat class could be attributed to differences between farms.

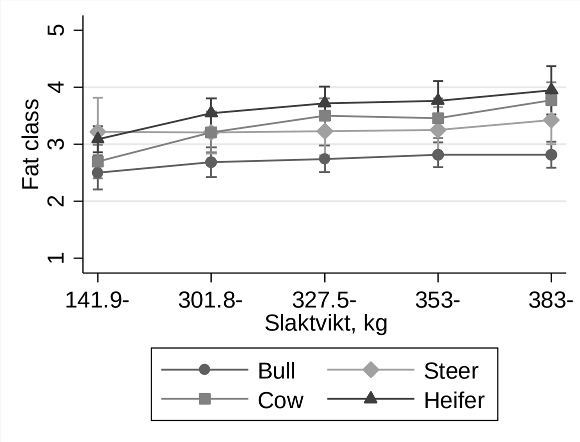

Figure 14. *Marginal means of fat class for different slaughter animal categories at different slaughter weights, according to a multivariable statistical model. Class is indicated on the original scale. The bars are 99% confidence intervals.*

Meat quality

Table 5 shows descriptive statistics for continuous variables regarding meat quality at both slaughter plants.

Table 5. *Overall descriptive statistics for continuous variables representing meat quality.*

Variable	Number of observations	Median	Interquartile range	Mean	SD
Lightness	543	34.1	4.73	34.4	3.45
Redness	543	20.0	1.94	20.0	1.61
Yellowness	543	9.28	1.89	9.32	1.48
Final pH	546	5.47	0.17	5.50	0.16
Weight loss at thawing, %	537	5.52	2.56	5.65	1.86
Weight loss at cooking, %	533	19.7	3.57	19.6	2.81
Shear force, N	381	40.0	13.9	41.9	12.7
Compressive load, MPa	378	17.2	7.62	17.9	6.12
Fat content, %	292	19.2	18.9	22.2	13.9

The final meat pH did not differ significantly between the slaughter plants. There was no clear association between final pH and the animal's emotional expression at the start of driving or with the way to drive the animals. Animals displaying clear stress behaviour had a slightly lower pH, and animals that did not exhibit any stress behaviour at all had a higher pH. The final pH tended to increase with the transport distance of animals staying overnight at the stationary plant, but the corresponding relationship was not found in animals that did not stay overnight. On average, the final pH was slightly lower in animals subjected to overnight lairaige. The percentage of animals with a final pH above 5.8 at cutting was 15% at the mobile plant and 7.7% at the stationary one. There was no significant association between any of the background variables and the risk of a final pH above 5.8 in the multivariable model. According to the model, 75% of the total variation in the risk of a high meat pH can be attributed to differences between farms.

The weight loss at meat thawing was slightly larger at the stationary plant but there was no clear differences between slaughter animal categories. At the stationary plant, the weight loss at thawing increased slightly with increasing form class, which was not the case at the mobile plant. At both plants, the weight loss during thawing decreased with increasing marbling. There was a tendency of decreasing weight loss during thawing at longer transport distances in animals not staying overnight at the stationary plant, as well as on average in animals that stayed overnight compared to those that did not.

The weight loss when cooking the meat was on average slightly higher in bulls than other slaughter animal categories. At both plants, weight loss at cooking decreased with increasing fat class and with increasing marbling. There was a tendency to a reduced weight loss during cooking at longer transport distances in animals not staying at the stationary plant, as well as on average in animals that stayed overnight compared to those that did not. Bulls had a slightly lighter and cows a slightly darker meat than other slaughter animal categories. The redness and yellowness of the meat were relatively similar in different slaughter animal categories.

Weight loss during thawing and cooking were relatively weakly correlated with each other (Spearman rho=0.23; p<0.0001). Final meat pH was negatively correlated with weight loss at thawing (rho=0.30; p<0.0001) but not with weight loss at cooking.

According to a multivariable model, weight loss when thawing is expected to be 1.2 percentage points lower at the mobile than at the stationary plant (p<0.0001). According to the model, one can also expect a 1.4-2.1 percentage points lower weight loss in summer than during other seasons (p<0.0001) (Figure 15). The weight loss at thawing is expected to decline significantly with increasing age (Figure 15). The weight loss at cooking is expected to be slightly higher in bulls than steers and heifers. According to the models, 43% of the total variation in weight loss during thawing is attributable to differences between farms. The corresponding percentage for weight loss at cooking was 17%.

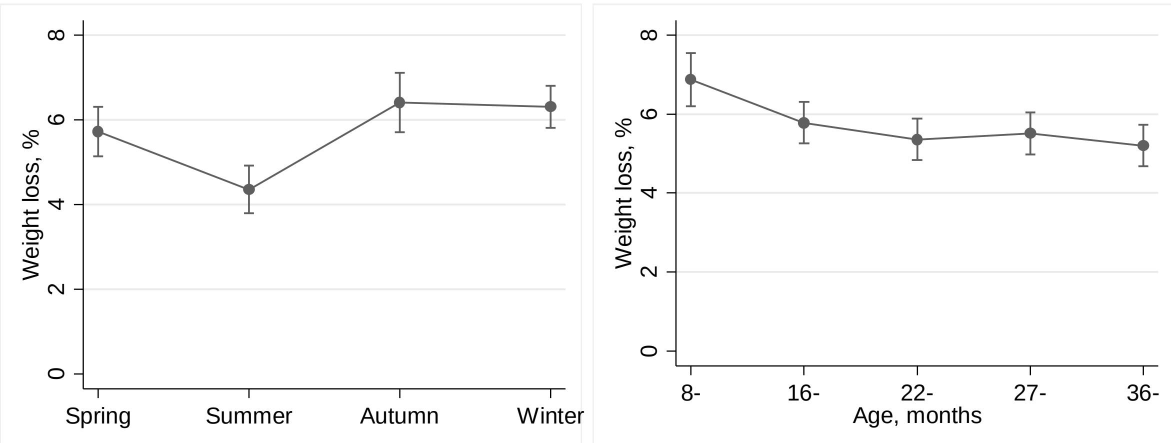

Figure 15. *Estimated marginal means of weight loss thawing of the meat for different seasons (left) and animal ages (right), according to a multivariatble statistical model. The bars are 99% confidence intervals.*

Shear force and compressive load were slightly higher at the stationary plant. At the stationary plant, the compressive load was highest in cows and bulls; otherwise the differences between different slaughter animal categories were marginal. At the mobile plant, animals regarded as hesitant prior to being driven had higher, and animals considered as nervous even higher, compressive loads. The same pattern was not seen for shear force. There was no clear association between meat texture and the transport distance to the stationary plant, but shear force and compressive load were slightly higher in animals staying overnight at the stationary plant.

Shear force and compressive load were weakly but significantly correlated with each other (Spearman rho=0.20; $p<0.0001$). Weight loss during thawing and boiling were slightly correlated with each other (rho=0.23; $p<0.0001$) and with shear force (rho=0.22 and 0.19, respectively; $p\leq0.0002$), but not with compressive load ($p>0.05$).

There was no significant association between any of the background variables and the meat shear force in the multivariable model. However, the compressive load is expected to be 1.2 times higher at the stationary plant than at the mobile one (p=0.0006). There was also a decreasing trend during the calendar year; the compressive load is expected to be 1.3 times lower in winter than in spring ($p<0.0001$) (Figure 16). According to the model, 42% of the total variation in shear force can be attributed to differences between different farms. The corresponding percentage for compressive load was 22%.

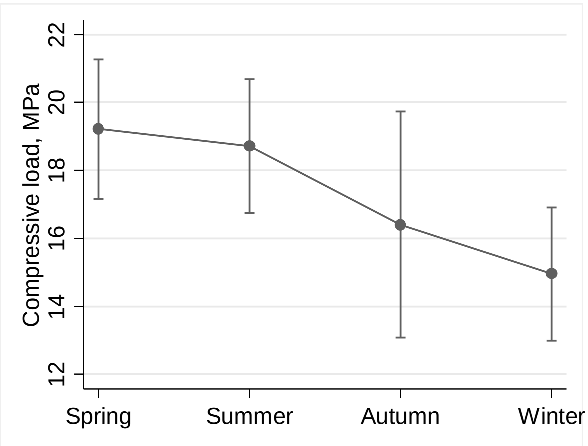

***Figure 16**. Estimated marginal means of compressive load in the meat for different seasons, according to a multivariable statistical model. The bars are 99% confidence intervals.*

Discussion

This project shows the importance of calm animals when driving to the stun box begins, an appropriate layout of premises, driveways and equipment, and good handling of the animals during driving, stunning and bleeding. The relatively limited differences between the two studied slaughter plants suggests that in mobile slaughter, a level of animal welfare and meat quality can be achieved which is in line with large-scale stationary slaughter. The project does not support the idea that animal welfare or meat quality is better with one or the other way of slaughtering.

Transport and lairage at the slaughter plant

A longer transport distance seemed to increase the likelihood of one or more active driving actions and for driving in an inappropriate manner. At the same time, longer transport distances seemed to reduce the likelihood of one or more stress behaviours and for a clear stress behaviour, which is somewhat contradictory. A longer transport distance also seemed to lower blood levels of cortisol and lactate slightly. Overall, however, the length of the journey did not seem to influence animal welfare or meat quality in any decisive way. A negative effect of transport to the slaughterhouse is not primarily due to the transport distance, but on loading and unloading conditions, the number of stops along the way, the way the transport vehicle is being driven, its interior design, and possibly the transport time (Dalla Villa et al., 2009), but these data were not available in this project.

At the stationary plant, animals that stayed overnight (about one animal of three) appeared to be at greater risk for one or more stress-related behaviours and high levels of blood cortisol, possibly indicating stress just before the slaughter. The tenderness of the meat was also deteriorated in overnight animals. At the same time, however, these animals had a somewhat lower lactate level and a low final meat pH, which appears contradictory and is difficult to interpret. An association between overnight stay and reduced animal welfare and meat quality could possibly be explained by the fact that overnight animals were also transported a longer distance before being housed at the plant, which in itself seems logical. Overnight stay also seemed to be associated with a shorter sticking time (time between stunning and sticking), which is also difficult to explain. However, according to the statistical models neither transport distances nor overnight lairage at the stationary plant was shown to be significantly associated with the outcome variables. Fällström (2011) found only a limited impact of overnight lairage on stress-related animal behaviour during subsequent driving and stunning at a Swedish slaughterhouse. This project did not cover the housing conditions at the plant during the overnight stay.

Overall, however, it seems reasonable to strive for a reduced proportion of overnight animals, while overall transport conditions need to be improved to reduce the animal's need for recovery at the plant before the slaughter. It is estimated that almost half of all cattle in Sweden stay overnight at the plant before being slaughtered.

Generally speaking, the planning of Swedish slaughter transports is largely manual, which means that it will not always be optimal. Research has shown that transport distances can be reduced through more strategic planning and optimisation using appropriate software (Algers et al., 2006; Moen et al., 2009; Håkansson et al., 2016). With a retained structure of the Swedish slaughter industry it was shown that the total slaughter transport distance for cattle could be reduced by 40%. If the farms delivered to the most close plant, it was estimated that the reduction could be 60%. Strategic transport planning also increases the ability to deliver the animals to the plant just before they are slaughtered, thus avoiding some overnight stays.

Driving and animal behaviour

Most animals were driven a few times and only a small number of animals were driven many times. Similarly, there was a smaller number of animals that exhibited many stress-related behaviours, while most only showed few such behaviours. On average, the animals showed 8.5 (median 7) stress behaviours in the driveway and stun box. Only 3.4% of the animals passed the driveway completely without displaying stress-related behaviours, which suggests that almost all animals experienced the slaughter procedure as at least mildly stressful. At both plants, touching and patting were the most common ways to drive the animals actively by hand and patting was the most common way of driving with a tool. The most common stress-related animal behaviour in the driveway was moving backward, followed by turning around, as well as defecation/urination at the mobile plant and vocalisation at the stationary plant. In the stun box, slipping, turning around and moving backwards were the most common animal behaviours. At the mobile plant there was a significant association between a large number of driving actions and many stress-related behaviours in the driveway, but the same connection was not found at the stationary plant. The animals that moved backwards or turned around in the driveway were more often driven more than once and in an inappropriate way, comparing with animals without these behaviours.

The proportion of animals driven in an inappropriate manner was significantly larger at the mobile plant than the stationary. At the same time, the proportion of animals that were not driven at all was significantly higher at the mobile plant than at the stationary one. Ideally, the design of the driveway will facilitate the propulsion of animals to stunning. It will also make it easier for staff to utilize the animals' natural flight behaviour when driving by placing and moving the body at the correct distance and angle to the animals. Solid walls in the driveway are favourable as they reduce the risk of animals being disturbed by humans, animals or objects near to the driveway (Grandin, 1997). Very high solid walls, however, make driving difficult because the animals do not see the stockpersons above them. Under such conditions, a raised platform alongside the driveway can facilitate handling.

Logically, a longer driving time should allow the stockpersons to perform more driving actions and the animals to perform more behaviours. For example, an inadequately designed driveway should result in a longer driving time, more driving actions and more stress-related animal behaviours. On the other hand, a low line speed can result in fewer driving actions and stress behaviours because the animals are less stressed, even though the driving time is longer. A long driving time as a result of a consciously low line speed can thus contribute to good animal welfare. Coleman et al. (2012) found that a pressed work situation due to an experienced lack of control and time was associated with more rough driving. This leads to the question of whether the frequency of driving and animal behaviour should be expressed as a pure number (regardless of the time) or as the number per unit of time, such as the number of driving actions per minute. The absolute numbers probably give a picture of the overall impact on the animals in the observed driveway section, and they are more easily comparable to the results of other studies, such as Grandin (1998) and Hemsworth et al. (2011).

Differences in animal handling between different slaughterhouse stockpersons can be explained by differences in attitudes towards work and animals, knowledge of animal behaviour and skills in handling them. Coleman et al. (2003; 2012) showed that stockperson attitudes to work and animals affect animal handling. The degree of staff knowledge and skills can be expected to vary depending on the level of education, experience and temperament. The studies by Coleman et al. (2003; 2012) suggest that there is an opportunity to improve animal handling at slaughter by taking into account the attitudes of the staff in various educational activities. It has also been suggested that the slaughterhouse management has an important normative role (Grandin, 2013).

High noise levels are common in slaughterhouses, and can interfere with the animals and make animal handling difficult. In mobile slaughter, there may be conditions for achieving low noise levels outside the plant, which should facilitate driving. However, this may make the animals more sensitive to single sharp sound impressions. At the studied mobile plant, it was noted that strong noise from inside the plant sometimes disturbed the animals on the outside. It should be possible to create a system that enables the staff to communicate between the inside and the outside, thereby avoiding disturbing sounds in sensitive situations, for example by means of a light signal on the outside to show that a new animal kan be driven or, alternatively, a light signal on the inside to show that the noise level needs to be lowered.

Stunning and bleeding

Every tenth animal at the mobile plant was shot more than once, compared to only a few percent at the stationary. It is likely that the re-shootings were motivated by a suspected lack of stun quality at the first shot, rather than a routine and without good reason. Assessments of stun quality were not included in this project. Inadequate stunning at the first shot may in turn be due to difficulties for the operator to reach safely the animals in the stun box. At the same time, the time from the last shot to sticking was considerably longer at the mobile plant than at the stationary (102 and 44 seconds, respectively). In addition, the variation in sticking time was significantly larger at the mobile plant. At the mobile plant, the sticking time was longest in cows, animals with a high slaughter weight and animals considered to be nervous when driving from the inspection site began.

Until 2013, the sticking time was regulated by Swedish legislation, and at stunning cattle with a bolt gun a maximum of 60 seconds was allowed. Current EU legislation (European Council, 2009) states no maximum time limits but only that the stunned animal must remain unconscious until it is dead. However, the sticking time shall be regulated in the slaughterhouse's own standard routine. According to the standard routine for the studied mobile plant, the benchmark was a maximum of 120 seconds, and this time could be exceeded in only a few cases. During the study period it occurred in 16% of the studied animals. According to standard routines for the stationary plant, the sticking time should be less than 60 seconds and this time was exceeded in 3% of the animals.

Properly performed stunning with a penetrating bolt results in immediate and complete unconsciousness from which the animal does not wake up. Provided that the stun is good, the sticking time is relatively uninteresting from the point of view of animal welfare. However, it is known that the stun quality varies in practice; in studies up to 35% of the animals in Swedish slaughter plants have shown signs of an inappropriate stun quality (Atkinson and

Algers, 2009; Atkinson et al., 2013). The risk of a poor stun appears to be highest in adult bulls (Atkinson et al., 2013). For an incompletely stunned animal, a long sticking time is likely to cause considerable suffering in the form of pain, stress and anxiety (Grandin, 1998; Gregory and Shaw, 2000), although the exact degree of suffering is difficult to estimate. In practice, it is therefore important that the sticking time is not too long, especially if the stunning quality is doubtful. The combination of many re-shots and, in some cases, very long sticking times at the mobile plant in this project is therefore worrying from an animal welfare perspective. In any case, sticking times longer than 120 seconds should be avoided.

A likely explanation for the long and variable sticking times at the mobile plant is the design of the stun box, which made it difficult for a quick and secure chaining and hoisting of the body after stunning. About halfway through the study period, the stun box of the mobile plant was rebuilt to improve the function. However, sticking times remained about as long after the rebuilding. The work of chaining and hoisting newly shot cattle is risky as the animals can kick reflexively. A poorly designed stun box with resulting difficulties in quick hoisting and sticking results in increased occupational safety risks.

Carcass and meat qualities

The average conformation class was significantly higher at the mobile plant, although due consideration was given to animal factors such as age, breed type and slaughter animal category. The reason for this is unknown. The raters were educated by the Swedish Board of Agriculture, which also conducted unannounced control inspections approximately every two months. Nor was it in the slaughter company's interest to classify carcasses too high as it would increase the payment to producers.

In this project, the stationary plant, in contrast to the mobile one, used electrical stimulation of the carcasses. At the same time, the mobile plant applied pelvic suspension as opposed to Achilles hanging at the stationary plant. In most cases, the stationary plant also removed the loin from the hindquarters (including the sirloin, from which the meat sample was taken later), while the mobile plant hung hindquarters in one piece. However, both plants hung the meat for 7 days. The meat tenderness (measured as a low compressive load) was significantly greater at the mobile plant than the stationary. The difference is likely to be explained by the carcass treatment, especially the pelvic suspension (Lundesjö Ahnström et al., 2009, 2012).

Even the time from stunning to carcass cooling was on average longer and more varied at the mobile plant than at the stationary, which could possibly be explained by more irregular work routines.

Environmental and animal-related background factors

A statistical model showed that the weight loss of the meat at thawing was associated with both season and animal age, independently of each other. Thus, although the animals slaughtered in summer were younger than in other seasons, this did probably not explain that the weight loss in these animals was lowest.

Most of the outcome variables in the statistical analysis appeared to be related to the slaughter animal category, ie if the animal was a bull, steer, cow or heifer. The slaughter animal category was also associated with animal age; cows were generally older and bulls were somewhat younger than other categories. At the mobile plant, the cows exhibited the most investigative behaviour, as well as the longest driving and sticking times. Steers were shown to have a significantly lower risk of clear stress behaviour than the other slaughter animal categories at the stationary plant. Heifers also had a significantly higher number of stress behaviours in the stun box than steers in mobile slaughter and a significantly higher likelihood of clear stress behaviour in the stun box than steers. The cortisol levels were highest among heifers and lowest among bulls. Bulls and steers of beef-type breed had the highest conformation grading, while dairy cows had the lowest. Bulls also had the lowest fat class grading, the leanest meat (lowest fat content), the lightest meat and the lowest weight loss when cooking the meat. However, there was no clear association between slaughter animal category and meat texture.

At the mobile slaughter plant, 7% of the animals were considered to be significantly hesitant or nervous when driving to the stun box was commenced. At the stationary plant only a few obviously hesitant animals were seen. At the mobile plant, animals that seemed hesitant to driving and animals left alone in the inspection pen had slightly longer driving times than other animals. Nervous animals had longer times in the stun box until the first shot and longer sticking times, which may indicate that they were more difficult to handle. Obviously hesitant animals had higher blood levels of cortisol, while nervous animals had higher levels of glucose and lactate. Meat from nervous animals also had the highest compressive loads (but not the highest shear forces). Probably the pressure resistance describes the texture of the meat in a clearer way than the cutting resistance, because the measurement is made of more fibers and over a larger surface. These results emphasize the importance of good animal handling and calm animals before driving to stunning.

The relationships between weather conditions and animal behaviour at the mobile plant were surprisingly small. Cattle coming from a dark barn into bright daylight are often considered to react negatively because they experience difficulties to see properly before the eyes have adjusted to the light. An explanation for the lack of such effects in this project may have been that most animals had already been outside for a while before the observations began. Season was shown to have be significantly associated with the likelihood of more than one stress-related behaviour in the stun box; the likelihood of such behaviour was lowest in the spring which, however, has no obvious explanation.

Farm conditions can be assumed to have varied widely in many different respects, including among the farms that delivered animals to the stationary plant. According to the statistical models, the percentage of the total variability in the outcome variables between the farms was between 5 and 75%. The highest percentages were observed for the risk of a high final meat pH (75%), conformation class (72%), fat class (62%), risk of more than three stress-related behaviours in the driveway of the mobile plant (44%), weight loss at thawing (43%) and shear force of the meat (42%), which indicates that these outcome variables to a large extent were influenced by farm-related factors, i.e. factors that varied between the farms rather than than within each herd. Examples of farm-related factors may have been breeding strategies, housing conditions and routines for care, feeding and handling of the animals on the farm, grazing routines and herd health. In mobile slaughter, additional farm-related factors are the plants's position relative to farm buildings (distance, sunshine), ground conditions and occurrence of objects and various other interfering factors outside the plant. In stationary slaughter, the layout of loading facilities and transport conditions (type of vehicle, number of stops, driving mode, time) are added instead. In this project, the receiving slaughter plant was also a farm-related factor, because none of the farms delivered to both plants.

For the outcome variables where the percentage of variation at farm level was small, for example, the risk of more than one stress behaviour in the stun box (7%) and the risk of clear stress behaviour in the stun box (9%), the variation is instead assumed to be be due primarily to animal factors, varying from animal to animal on each farm. Examples of such factors were breed, slaughter animal category, age and temperament, but also the time of day. Judging by the estimated proportions, the farm factors had a relatively greater impact on animal behaviour in the driveway at the mobile plant than at the stationary one, while the opposite was true for the behaviour in the stun box. The reason for this is unknown.

Methodological aspects

From this project it is not possible to draw safe conclusions about differences between mobile and stationary slaughter of cattle in general, as only one plant of each type was studied and these can not be considered as representative of the respective ways to organise slaughter. The comparisons that can be made between mobile and stationary slaughter are therefore mainly related to the two specific plants that were studied in the project. Nevertheless, it is possible to identify some differences, seek explanations for them, and discuss improvement opportunities within the framework of the respective slaughter system. The decisive differences between the plants that could be detected were related to the condition of the animals prior to driving to the stun box, animal driving, re-shooting, sticking time, carcass grading and meat texture.

Direct comparisons of the two plants are complicated by the fact that the conditions differ in many respects. An explanation for differences between the two plants studied could be that the animals were handled in a mobile or stationary slaughter system, which is one aspect that this project intended to highlight. Other possible explanations are that the premises were differently designed, that the animal material differed, that the staff had different conditions for carrying out the work, that the line speed differed, that transport from the farm and overnight lairage only occurred at the stationary plant, that the mobile plant applied pelvic suspension of the carcasses while the stationary used an Achilles suspension and, last but not least, that stationary slaughter (including the studied plant) had a long history of development of interior design, equipment and methods, while mobile slaughter was a fairly new phenomenon, assuming that some development work remained.

The observations of the stationary plant only covered the time from the animals being driven into the stun box, not the transport from the farm or any longer stay at the plant. Therefore, the impact that the slaughter transport itself and the lairage might have had can not be estimated except if it affected the animals at the time they were studied. For example, transient stress when loading the truck on the farm was not necessarily seen at the slaughterhouse. On the other hand, heavy stress shortly before driving to the stun box may have affected animal behaviour, blood chemistry or meat quality later on.

Using the statistical models, relationships between different background variables (including slaughter plant) and outcome variables could be estimated after correction for all the other background variables that were tested. Background variables which, after testing, were not considered to have a significant impact themselves were not included in the models. Model results should be interpreted as expected associations if all the other variables in the models were kept constant – which is likely to be the most correct way of expressing the studied effects or relationships. For example, the estimated association between season and compressive load in the meat shown in Figure 16 is valid regardless of plant, time, slaughter animal category and age, because these variables were included in the model of compressive load.

Conclusions and recommendations

This project shows the importance of keeping the animals calm when driving to the stun box begins, that the layout of the slaughterhouse premises, driving routes and equipment are appropriate and that the handling of the animals during driving, stunning and bleeding is correct. There are conditions for good animal welfare and meat quality in both mobile and stationary slaughter of cattle. Based on the project, it can not be concluded that animal welfare or meat quality is generally better with one or another way of slaughtering.

Based on this project, the slaughterhouse managers are advised to take action to achieve the following:

- A reduced proportion of animals staying at the stationary plant, which can be achieved through transport optimisation using appropriate software, in parallel with measures to improve transport conditions.
- Improved animal handling at the farms and at driving into the stun box. At the mobile plant, well-designed permanent driveways are needed between the farm buildings and the plant, as well as trained farm stockpersons who handle the animals. At the stationary plant, a more effective driving into the stun box can be accomplished with a mechanical pushing gate.
- Improved design of the stun box at the mobile plant to facilitate fast and accurate shooting, hoisting and sticking of the animals, reducing the risk of re-shooting and shortening the sticking time.
- Possibilities for the staff to communicate between the inside and outside of the mobile plant, thereby avoiding disturbing sounds in sensitive driving situations. This could be achieved by means of a light signal on the outside to show that a new animal can be driven or, alternatively, a light signal on the inside to show that the noise level needs to be lowered.
- A more permanent set of producers of slaughter animals to the mobile plant to reduce the variation in farm conditions and animal qualities, as well as improve the possibilities to create well-functioning routines for on-farm slaughter.

Future research on animal welfare and meat quality in small-scale and mobile slaughter should take into account the importance of transport from the farm to the plant, lairage, driving methods and various ways of treating the carcasses. Stun quality should be assessed if possible.

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Acknowledgements

The authors would like to thank the two involved slaughter companies for providing an opportunity to carry out the project, especially the staff who assisted in various ways with the data collection in connection with driving, slaughter and cutting. Thomas Lyck, previously employed by the mobile slaughter company, contributed valuable information and ideas when the project was initiated. Marco Berta, Marlene Svensson and Emma Bragd at RISE Research Institutes of Sweden, Agriculture and Food conducted analyses of meat samples.

The project was funded by donations from Marie-Claire Cronstedts Foundation and the Swedish Animal Welfare Association. Basen AB and Caroline Ankarcrona contributed funds for meat analyses. The meat samples taken at the mobile plant were paid by the slaughter company.

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